The S-200 Angara/ Vega/ Dubna[1]

Following the installation of S-25 Berkut around Moscow, the deployment of SA-75/S-75 Dvina/Volkhov and S-125 Neva around Leningrad and other cities the rapid technological development of the Cold War raised new challenges for the air defense of the Soviet Union. USA developed and manufactured the Mach 2 capable B-58 Hustler intercontinental bomber and the Mach 3 capable B-70 Valkyrie was under development. Shooting down these bombers if they apply only noise jamming would be close to impossible (or impossible) with existing SAM systems because of their speed. The interceptor fighters (Su-9, Su-11, Su-15, Tu-128 and MiG-21P) of the PVO also were inadequate regardless they had radar guided air to air missiles in the early and middle of '60s, a successful intercept would require very precise ground controlled interception and very skilled pilots.

The AGM-28 Hound Dog could be launched from B-52; each bomber could carry two jet engine powered missiles.

Eventually the high speed bombers proved to be a dead end because the appearance of the developed new S-200 SAM and the Mack 2.5+ capable MIG-25 Foxbat interceptor. Instead developing new high speed and super expensive bombers it was easier and cheaper equip the existing subsonic bombers with missiles. These missiles had enough long range to stay outside of range of SAMs and fly as far as possible from fighter bases to reduce the chance of successful interception.

Such supersonic missile was the very long range (640-1200 km depending on attack profile) AGM-28 Hound Dog in US inventory , the later and smaller AGM-69 SRAM and the Blue Steel[2] missile for Victor and Vulcan bombers of UK. The AGM-28 could fly with Mach 2 at high; the Blue Steel (on paper) could accelerate at terminal phase to Mach 3. (The air launched AGM-48/GAM-87 Skybolt ballistic missile was cancelled.) The Mach 3 capable AGM-69 SRAM had much shorter range (about 200 km at high altitude) than AGM-28 but the smaller FB-111B could carry two, the B-52 could carry 20 pieces of them (externally on two wing pylons – six missiles on each pylon – and internally on an eight-round rotary launcher mounted). Regardless AGM-69 SRAM had much shorter range comparing to AGM-28 but the SRAM was faster and so many could be launched missiles could easily penetrate the Volkhov + Neva SAM rings. The SRAM was too fast even for interceptor fighters only the B-52 could be downed before the launch.

The task was for Soviet engineers – both for SAMs and fighter designers – creating such air defense which can deal the all the new threats the mentioned threats above.

One of the advantages of the planned new long range SAM system was capable to area defense. So far all the older SAM system has such engagement range which required SAM rings around the defended objectives/cities with many SAM sites included have only some target channels to one direction. It was not so hard penetrate such air defense especially with fast bombers and missiles. Comparing SAM rings with

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[1] http://infowsparcie.net/wria/o_autorze/wsp78pr_s200we.html
http://infowsparcie.net/wria/o_autorze/pzr_s_200_w_880n.html

[2] The Blue Steel proved to be very unreliable.

S-75 + S-125 batteries a new SAM system with 150-300 km maximal engagement range can allocate its target channels freely in any direction and it can defend more than one objective. If such a SAM system with 6 target channels is installed next to a city it can engage targets on the opposite side of the defended objective just as almost long range as on its own side, the 6 target channels are available any direction. While SAM systems with only 30-40 km range are not able to this it requires deploying much more SAM batteries. We can see this difference on the planned sites of Dal system and S-75 Desna SAM systems.

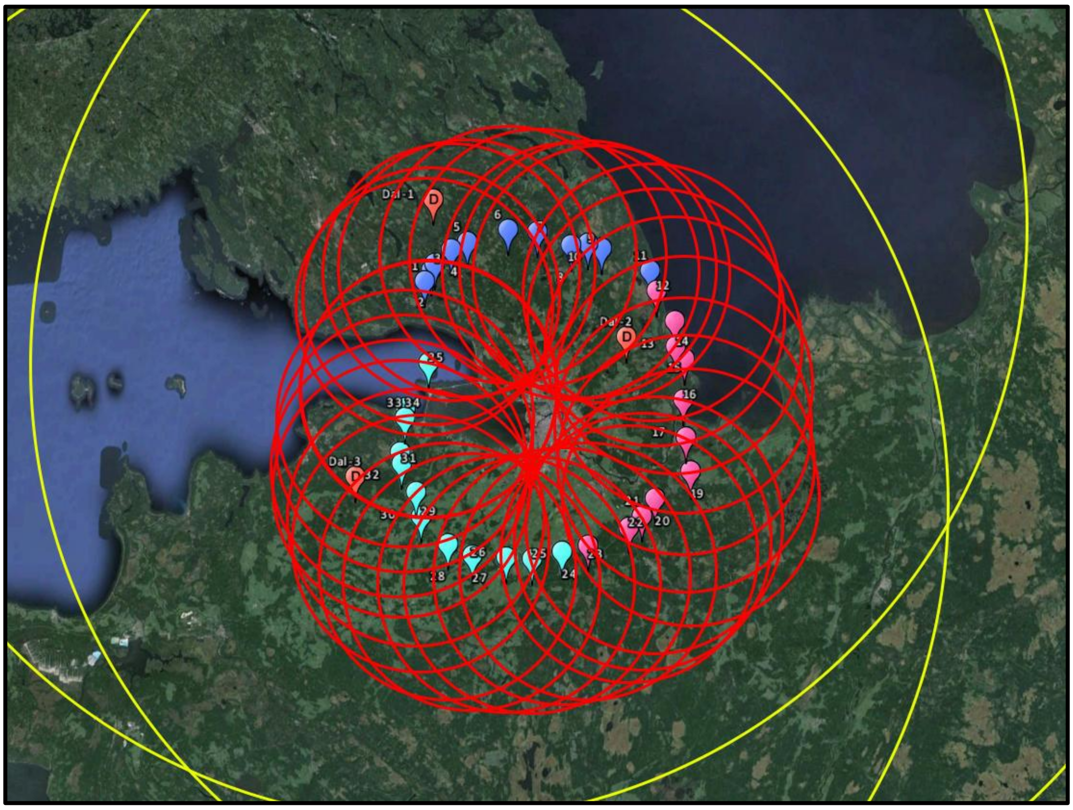
P. F. Batitskiy demonstrates what the country's air defense system must be.

The commander of the PVO illustrates how big SAM system is needed for defending the Soviet motherland.

The S-200 system was developed by the same KB-1 bureau leaded by Raspeltin what designed the S-75 and S-125 SAM systems. The S-200 had the biggest engagement range among the Cold War SAM systems which used conventional, non-nuclear warhead and remained the record holder even after introducing the S-400 (SA-21).[3]

(The US designed BOMARC had higher range but was operational only with nuclear warhead. The S-200 also could use missile with nuclear warhead but it was not a mandatory requirement, see later.)

Soviet Union never exported nuclear technology for ballistic missiles and special SAM missiles the USSR would hand over them in case of war the nuclear warheads for WPACT member countries. It was out of question to create such SAM system which can be used only with nuclear warhead.



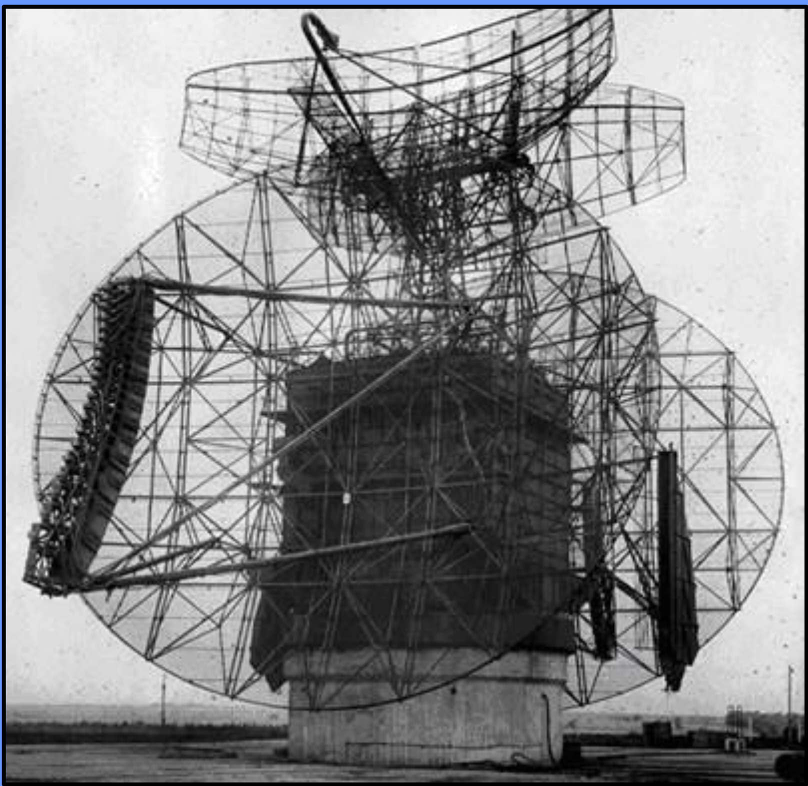
The planned engagement zones of the 5 Dal systems and the 33 S-75 Desna batteries around Leningrad.

[3] In 2018 still has only the 48N6DM missile with 250 km range, the Dubna had 300 km engagement range. The S-400 system will have greater range but only with the new two stage 40N6 missile with active radar guidance which has not been entered into service.

The aim of initial development was creating a new SAM system at least with 160 km maximal engagement range which is cheaper than the S-25 Berkut and can provide all-round defense. From this basis started the development of the Dal[4] system but the project was unsuccessful and was cancelled. 5 Dal batteries were planned to build along with 33 S-75 Desna (SA-2C) batteries, this was called S-100 "Leningrad" system. For the S-100 was designed the first automatized command system the S-100V Asurk which would coordinate the operation of Dal and Desna batteries.

The Dal system was developed by the OKB-301 bureau leaded by S.A. Lavochkin. Because of the location of installation got from western agencies the "Leningrad" designation.

5 Dal sites was planned to build around Leningrad instead rival S-200 system with 2, 3 or 5 target channels per site. The 5N21 radar (see below) was designed with pair of large antennas with 18 meter diameter. The very complex antenna system with 15 RPM would provide 360 degree target acquisition and guidance data for missiles, it was planned with 10 target and 10 missile channels per batteries.



The planned missile designed with two stages and combined radio-controlled (RCG) guidance and active radar homing (ARH) guidance in terminal phase. The large antenna for active guidance with the specified long range leaded to a very large missile with 16 meter length and 8.7 tons launch weight. The Dal proved to be unreliable; the industry of Soviet Union was not able to support the high quality for the ARH seeker for the V400 missile. Eventually the Dal was cancelled and S-200 for selected in October of 1962 even some parts of the system – concrete building of the sites, radars, etc. – reached very high completion state.

To deceive the intelligence agencies of USA the manufactured V400 missiles from 1963 many times was displayed on Moscow Victory Parades regardless they never entered in service. Because of this public appearance got the designation from intelligence agencies the SA-5 Griffon.

[4] *http://infowsparcie.net/wria/o_autorze/pzr_system_dal.html*

For the S-200 system the semi active radar guidance (SARH) was selected instead the combined RCG + ARH of Dal because of the large specified engagement range the pure RCG was not feasible because, above 55 km range all missiles had to equipped nuclear warhead to be usable.[5] Because of the selected guidance method and specified long range the size of the missile was huge. The SARH guidance had upsides and downsides on the on the physical size and cost of the system which were the followings:

- The “brain” was in the missile not in the guidance comparing to Volkhov and Neva systems with used RCG and guidance station. For the missile of S-200 the fire control radar illuminates the target and based on reflection the missile calculates itself the guidance commands. This decision made expensive the electronics of the missile especially considering lack of solid state electronics which made very hard to design a compact guidance section.
- With SARH guidance one battery had only a single target channel but any quantity of missile could be guided in the same time because missiles were self-guided. (It has no sense to launch more than 2-3 missiles against a single target; practical limit was 3 missiles by the rules of engagement.)
- Because of the SARH guidance before the launch had to lock on the target with the missile. To being capable to this from long range large antenna needed which had strong impact on size and weight of the missile. Large missile diameter means huge drag, lots of fuel is needed for long range. The end result of the large antenna and the lots of fuel was such a huge missile which was comparable to a MIG-21 fighter aircraft.
- The missile was huge regardless of the liquid fuel propelled second stage – with very similar toxic fuel as was used to Volkhov – in terms of technical operation was one step backward comparing to Neva which had only solid fuel propelled stages. It was necessary to use the liquid fuel to reach the specified engagement range because it had better thrust/weight ratio comparing to solid propellant rocket engines. For exchange handling such missiles is a harder and more complicated task.[6] The S-200 was the last SAM system in the Soviet Union which was designed with liquid fuel rocket engine.
- The specified range not only leaded to a large missile but rest of the main elements of the system also large and heavy which made totally static the new system similar to S-25 Berkut even some parts of the equipment were on towed vehicles. (Comparing to Berkut at least had much larger engagement range and could launch missiles to any direction.)

The S-200 system introduced many new features it was first Soviet SAM system which used continuous wave (CW) target illumination (like the American HAWK or the later designed Soviet army air defense system the 2K12 Kub) and had digital computer with magnetic core memory. The computer had a 64 kHz (0,064 MHz) 16 bit CPU with 256 byte RAM and 4096 byte (4 Kbyte) ROM. The computing capability even in the ‘70s was laughably weak after solid state electronics was introduced but in that time was considered good.

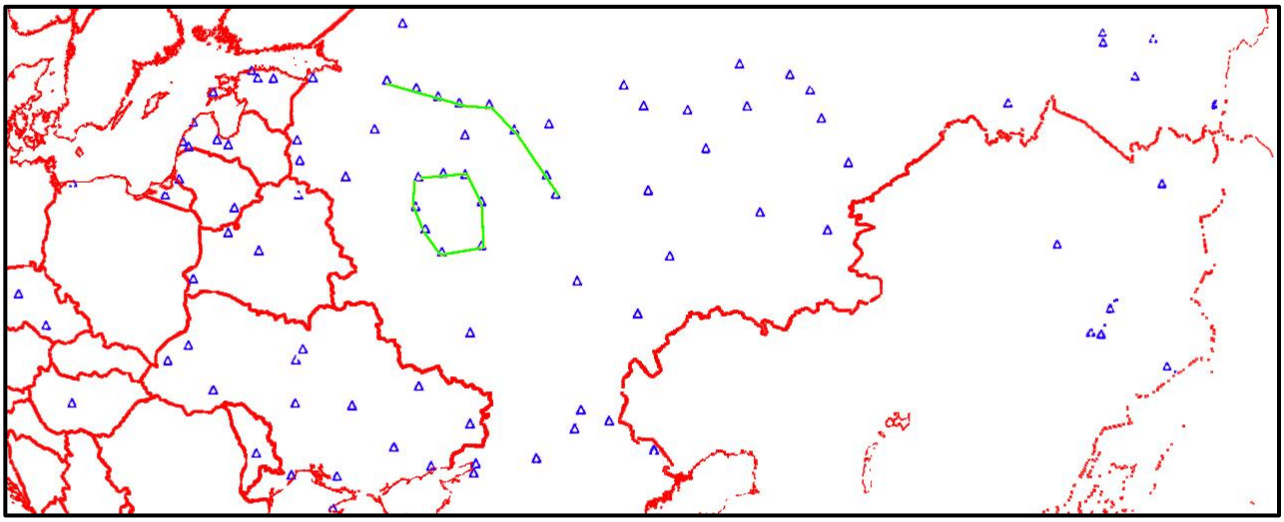
The installation of the S-200 system started in 1967 the first site was built near Tallinn (Estonia) thus it was called the “Tallin” system in the west. During the service S-200 systems got upgrades which leaded to three main subvariants. The first was the S-200A Angara (SA-5A) then the S-200M Vega-M (SA-2B) and finally the S-200D Dubna (SA-5C). The exported S-200VE Vega-E (SA-5B) was used by the whole Warsaw Pact except Romania; Vega was exported between 1984 and 1986 in WPACT countries. Outside the Warsaw Pact the

[5] *At the time of development in USSR mass production of small nuclear warhead was to possible the allocated resources tried to manufacture enough large thermonuclear devices for ballistic missiles. In case all missiles would have nuclear warhead it would make just more expensive the system.*

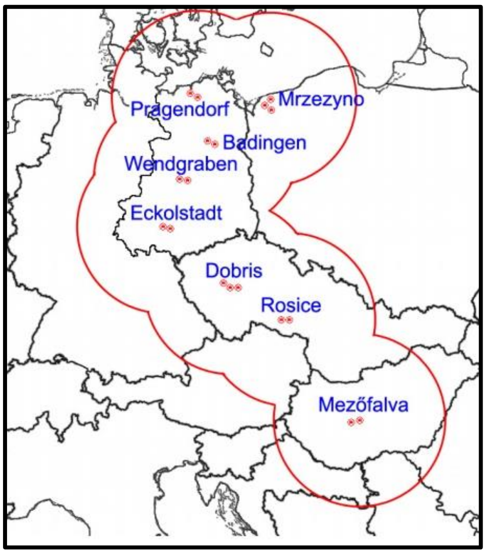
[6] *It is not a coincidence never was any liquid fuel propelled air to air missile.*

Vega was exported to Libya, Iran, Syria and North Korea between 1985 and 1991. (Considering S-300PM also was exported in very limited qty. the export of S-200 happened much later than S-75/S-125 export.)

In the Soviet Union about 130 S-200 sites were built typically 3 SAM batteries per sites but also existed sites with only 2 batteries and with 5 batteries either. The S-200 sites defended the whole airspace of Soviet Union from east of Ural mountain with overlapping engagement zones. Around Moscow 8 sites were built in ring formation from about 100 km from the capital city. Was another 800 km long SAM barrier with 9 more sites about 400 km north from Moscow. In Asia only the most important cities and objectives got 1-2 sites.



Above are the S-200 sites in the Soviet Union, Hungary, Poland and Czechoslovakia.



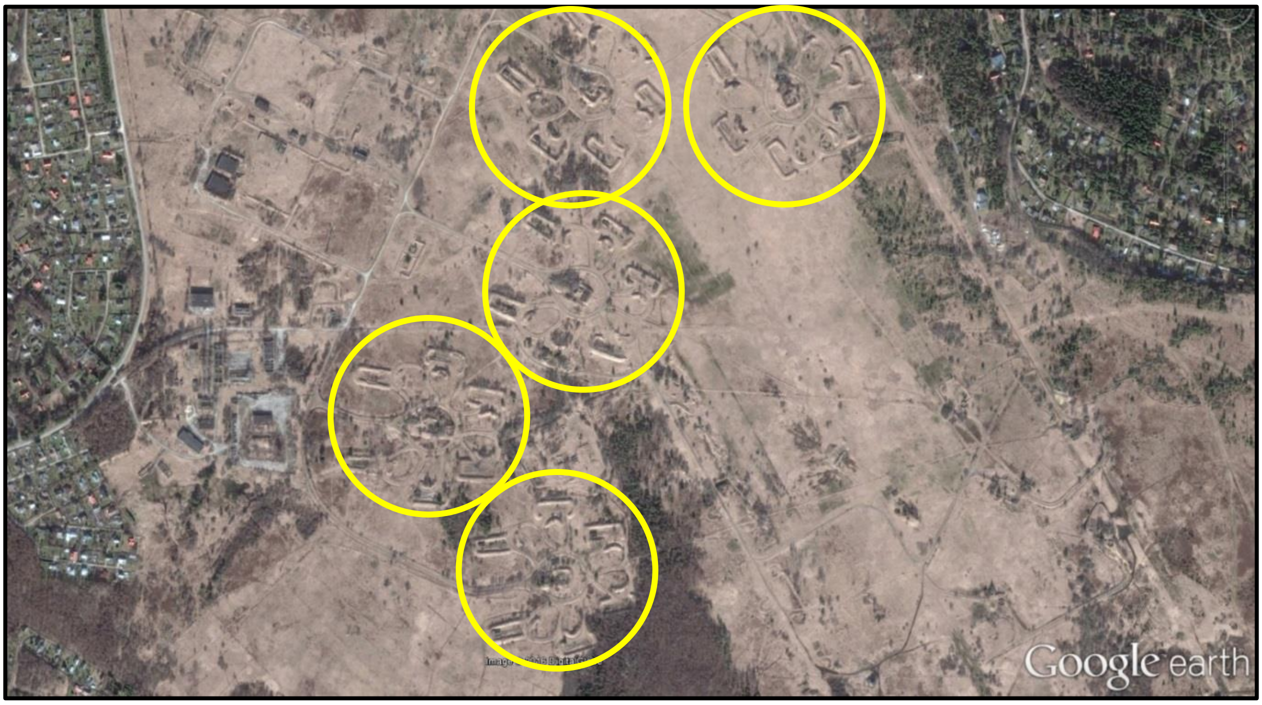
The structure of an S-200 site is different from the smaller range S-75 and S-125 sites One S-200 site had more than one SAM battery but the batteries had shared equipment. Each S-75 or S-125 batter had their own target acquisition radars but for the S-200 batteries the target acquisition radar was shared while each battery had their own fire control radar.

The Vega barrier of the Warsaw Pact was formed at 8 sites with 18 batteries; only two sites had three batteries Mrzezyno and Dobris.

Was no S-200 site with a single battery, at least two batteries were installed for a site. In the Soviet Union sites with 3 batteries were typical but in WPACT countries because of financial reasons mostly only two battery sites were built. The only finished site with 5 batteries was the first next to Tallinn[7] but according to the documents of CIA[8] building more than one 5 battery site building was started. Maybe CIA was wrong or the plans in the USSR changed. (Was not any site with 4 batteries except a very special one, see later.) Outside of the territory of the USSR 3 Soviet sites were built 2 in Mongolia and 1 in East Germany.

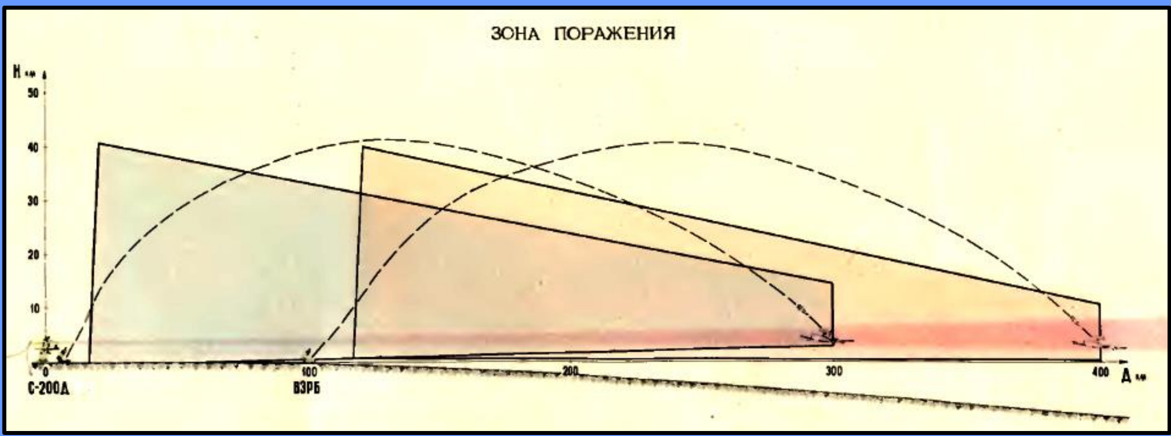
[7] https://goo.gl/7HWBhE The satellite view is composed using images from two different seasons but using Google Earth and checking older images we can see the S-200 site which has been dismantled today.

[8] See in the attachment (The Soviet SA-5 deployment program), on page 8. It is interesting to see the inaccuracy of the data and also because of the false predictions. The capability of the system is poorly estimated as well as the future of the S-25 Berkut which retirement was forecasted after introduction of S-200 but it happened only the early of '80s.



Above is the former S-200 site from east of Tallinn between Naage and Türisali. It is clearly visible the launcher locations of the 5 batteries, each with 6 launchers. The rest of the battery with roads, railways and foundations are barely visible.

At Vladivostok was an S-200 site with 3 batteries. It got an additional battery which was moved farther away from the rest of the site (VZRB). The reason of this site was the SR-71 recon flight from Kadena which sometimes unintentionally violated the airspace of the USSR. Technically one S-200 battery was moved ahead from the main site. This new site got a K3 launch preparation cabin, 6 5P72 PU launch rails, 12 5Yu24ME ZM missile loaders and the 5F20 remote connection cabin. This installation was totally unique this was the only site with such configuration. (Very likely the specified 380 km engagement range of the S-400 is originated from this setup.) The engagement zone of this special site is below.[9]



The relocation of S-200 was only theoretically possible but in reality the infrastructure demand denied the relocation. Except Libya operators used without reserve or additional sites the S-200 Vega. Deploying to field the S-200 was not possible due the size and weight of the equipment. Libya built S-200 sites at 8 different locations for 17 batteries in total.

9 http://historykpvo.narod2.ru/ *ТТХ системы С200Д- с200д раскл, page 1.*

The sites were in the following locations with the maximal available space for batteries:

Tripoli
Site with 2 batteries, active site
Site for prepared 3 batteries, empty

Zlitan
Site with 2 batteries, active site

Surt
Site with 2 batteries, active site

Benghazi
Site with 2 batteries, active site
Site for prepared 2 batteries, empty
Site for prepared 2 batteries, empty

Tobruk
Site for prepared 2 batteries, empty

In theory is possible to relocate as way the S-200 batteries to have site with 1 battery but in this case not all sites can have long range target acquisition radar. (See later about the equipment and layout of a site.)

Above are the locations of the S-200 sites in Libya.

Not only Libya but Iran also operates differently (in 2017) the S-200 SAMs comparing to standard site layout and equipment quantity. Between 1990 and 1991 2x3 batteries were purchased (for two sites) but later the batteries were split from their original organization structure. On some sites launch rails can be (re)loaded only from truck loaders (TZM) on other sites similar hardened sites are built with railway moving loaders (ZM) as in the WPACT countries and the Soviet Union. Because are more S-200 locations than two not all sites have the long range target acquisition radar likely they get target coordinates via data link. Some images about the site are on the links below.
http://forum.index.hu/Article/viewArticle?a=143596771&t=9120320
http://forum.index.hu/Article/viewArticle?a=143596991&t=9120320
http://forum.index.hu/Article/viewArticle?a=143597035&t=9120320
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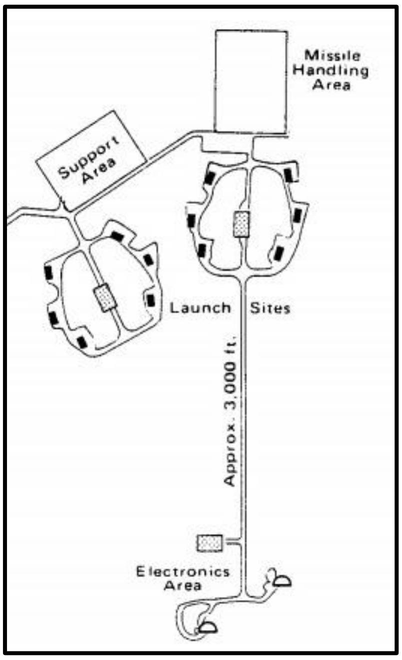
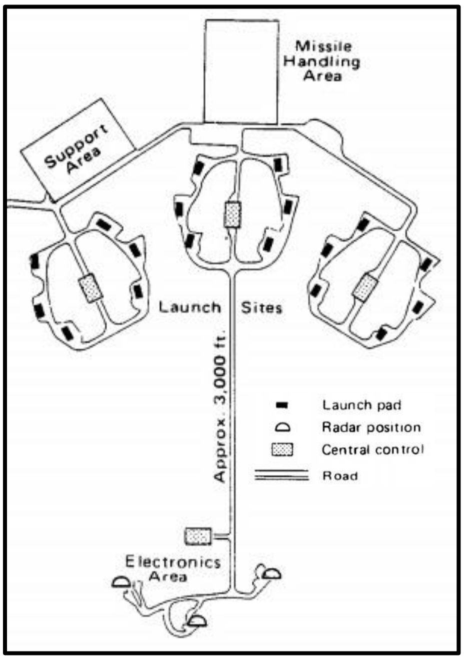
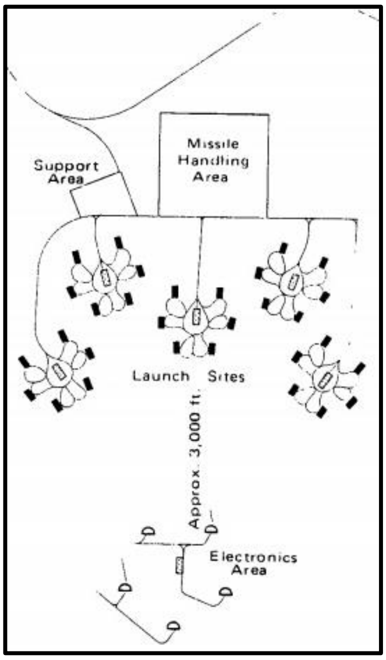
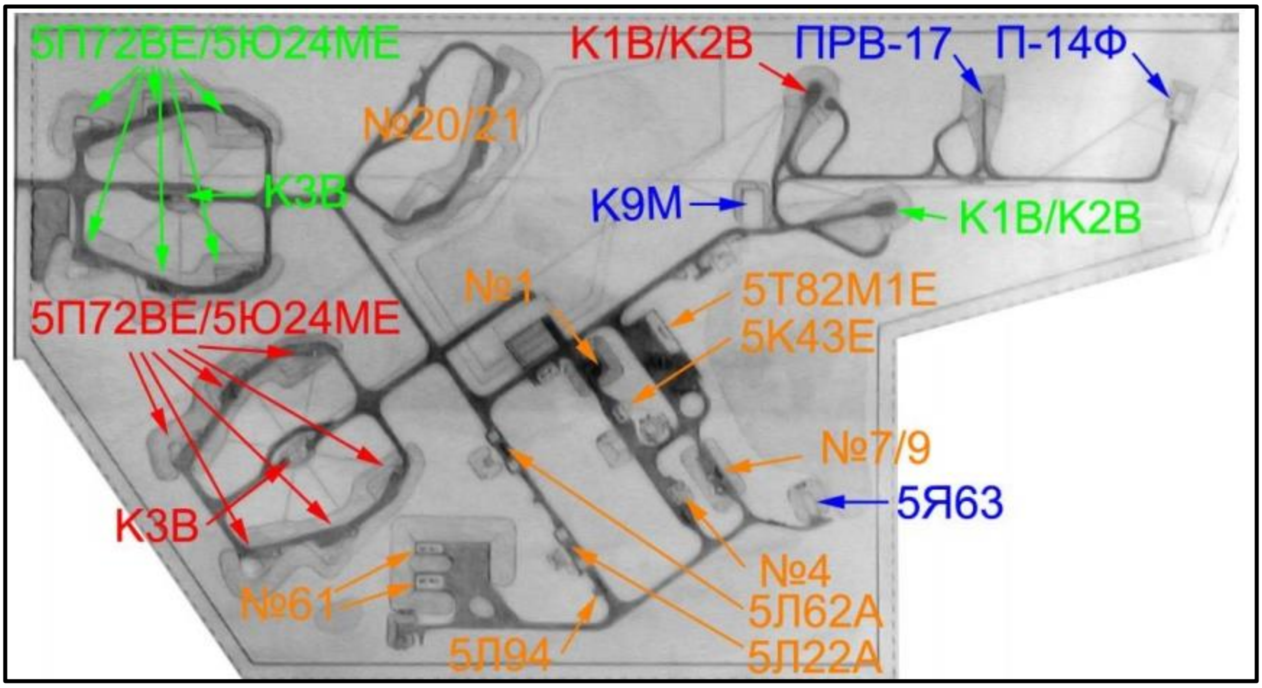






Above are the typical layouts of S-200 sites with 2, 3 and 5 batteries. The fire control radars of the batteries were about 1 km from the launchers. In the attachment are original Russian layout drawings about sites.

In Hungary an S-200 Vega site was installed in 1986 with two batteries. Through of the layout of this site is explained the composition of the S-200 system as an exact example.



Equipment of the battalion (site)

- **К9М:** K9M battalion management center cabin
- **П-14Ф:** P-14F Oborona (Tall King-B) target acquisition radar
- **ПРВ-17:** PRV-17 (Odd Pair) height finder radar
- **5Я63:** 5Ya63 microwave relay connection to the IADS system

(1.), *(2.)* Equipment of firing batteries:

- **K1B/ K2B:** K1V, 5N62VE target illuminator (RPC)
  K2V fire management cabin (fire control cabin)
- **K3B:** K3V launch preparation cabin
- **5П72BE/5Ю24ME:**
  6 pcs 5P72VE PU missile launchers (per battery)
  12 pcs 5Yu24ME ZM missile loaders, each carrying one missile for a total of two reserve missiles per launcher

Equipment of the technical battery:

- **5T82M1E:** 6x TZM missile truck transporters per battery (in total 12x)
- **№1:** storage area for 6pcs V880E missile second stages
- **5K43E:** AKIPS, missile systems checking area (for 2nd stages)
- **№7/9:** storage are for booster stages and warheads
- **№4:** missile assembly area (joining 1st, 2ndstage, and the warhead)
- **№61**: buildings holding 4 pcs 5Ya83 assembled missiles storage rail per battery, (total 8) capable of storing 3 assembled missiles per rail. (altogether 24 assembled missiles)
- **5Л94**: 5L94 high pressurized air filling station
- **5Л22A**: 5L22A "G" material (fuel) filling station
- **5Л62A**: 5L62A "O" material (oxidizer) filling station
- **№20/21**: missile defueling, and decontamination area

The site with two batteries is occupied an area of 1.1km², ten times that required by earlier S-75M Volkhov system.[10] The crew of the S-200 site with all operators, technicians, guards and logistics was about (nominally) 600 men. The size of crew demonstrates well how complex the system was and the cost of maintenance and operations not mentioning the acquiring the system. Hungary paid 500 million Rubles for it. The S-200 was a very decent system even in the '80s but considering the general technical level and complexity after introducing the S-300 family became outdated in the '90s especially when longer range subvariants of S-300, the PM/PMU1 (150 km) and PM2/PMU2 (200 km) became available. Their engagement range were enough big to provide similar capability as Vega but with much more flexibility and less equipment. S-200 was totally static while SAM S-300 is a fully mobile system (even it was designed for homeland defense) except the very first PT subvariant.

5T82 TZM missile transporter / loader

[10] *https://sites.google.com/site/samsimulator1972/home, S-200VE Vega-E (SA-5B Gammon) Long Range Surface to Air Missile System Simulator Documentation.*

Above left 5P72 launch rail, the railway which leads to the launcher is clearly visible. The crew is next to the missile provides good reference about the size of the missile. Above right is the 5Yu24 ZM railway loader during the reload process.

In normal operation because of the size and weight of the missile reloading the launchers (PU) is carried out from railway loaders (ZM) remotely operated. For each PU are assigned two ZM loaders therefore after launching the first 6 missiles from the PUs 12 another can be reloaded “quickly”, the reload takes 2 minutes. In case missiles are depleted from ZMs further reload is possible only from the loader trucks (TZM) which is a much slower process it takes about 8-9 minutes. The reload process can be started just after launching a missile while the missile is still on way to target. At maximal engagement range flight time to impact point is 3-3.5 minutes therefore in case of long range engagement the launchers could be reloaded from ZMs before the second salvo.

Loading the whole system from empty state can be done only a very specific way. The PU is loaded from TMZ which unload the missile to ZM. In combat PUs are reloaded first from ZM and in case all ZMs are empty only TZMs can be used. In case a missile has to be taken out from ZMs – for example because of maintenance – an empty PU is needed because only ZM --> PU --> TZM moving is possible, missiles from ZMs cannot be moved directly from ZM to TZM way.

In short the different load and unload processes are below:

- Loading the system with missiles from a totally empty state:
    1. TZM ----> PU ---> ZM (2 pcs ZM for each PU)
    2. TZM ---> PU after all ZMs have been loaded, in total 6x(1+2) = 18 missiles per battery
- In combat:
    1. Launch from PU, ZM ----> PU reloading, 2 missiles for each PU (2 min)
    2. After depletion of ZMs, only TZM ---> PU reload is possible (8-9 min)
- Unload missiles from ZM and PU:
    1. PU ---> TZM
    2. if a PU is empty can be done the ZM ---> PU ---> TZM way

In Hungary in peacetime readiness two missiles were on ZMs and 24 assembled missiles were stored in two №61 buildings and 8 disassembled missiles were in № 1/7/9 storage buildings.

The S-200 system similar to Dvina/Volkhov/Neva has different kind of radars for target acquisition, height finding and fire control. Each battery has its own fire control radar but the target acquisition and height finding radar are shared only 1/site is available. The target acquisition radar is the P-14F Oborona (Tall King-B) with 32 m wide and 11 meter tall antenna with 150-170 MHz frequency. Smaller, MiG-21 size targets can be detected about from 300 km against high flying intercontinental bombers detection range is about 600 km. The height finder radar is similar looking the PRV-13 of Dvina/Volkhov batteries but is much

larger the PRV-17 (Odd Pair) and it was not optional because of the very large engagement range of narrow beam of the fire control radar.

Above left is the PRV-17 (Odd Pair) height finder radar; above right is the P-14F Oborona (Tall Kind-B) long range target acquisition radar.

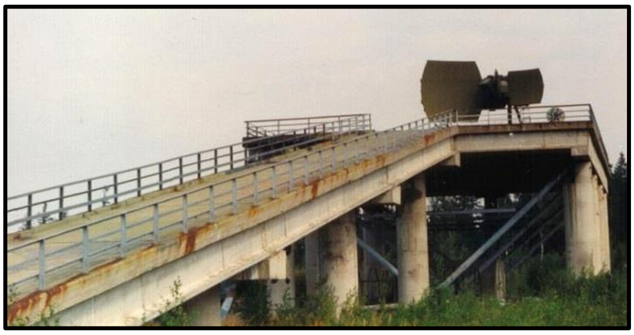
Regardless both of radars above are installed on towed vehicles their sizes demonstrates well none of them are mobile. The P-14F is so big and heavy it requires using brace cables to stand up. The minimal disassemble time of a battery in a scale of a full day but this is theoretical because except Libya none of the operators built additional sites for provide alternative locations for the system. Deploying on the field the S-200 is not possible.

The cabins of the S-200 system are the followings:

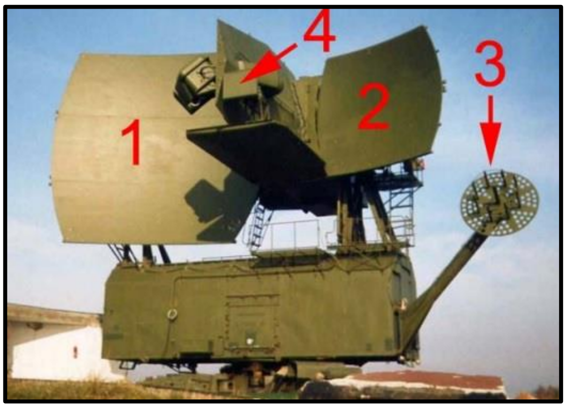
- K2V fire management cabin (fire control cabin). The crew of fire control radar (RPC) is in the cabin with the battery commander, the guidance operators and the launch officer. The K2V cabin is below the K1V (5N62VE Square pair) target illuminator radar this is why displayed with “/” above the schematic drawing of the site.
- K3V launch preparation cabin. Loading and unloading is remotely controlled (ZM --- > PU) from here as well as the preparation process before the launch.
- K9M battalion/brigade management center cabin. The site commander assigns the targets from this cabin to batteries using the data gathered by the P-14F and PRV-17 or what forwarded and shared by the automatized command posts/systems.

The example site (battalion) can be considered as standard two battery S-200 Vega site but some operators have different kind of S-200 sites where ZMs are not part of the system only TZM, truck loading is possible for example in Syria all S-200 sites lack ZMS. This made the system cheaper but the combat capability of the system is much lower because after launching the first 6 missiles the rate of fire is much lower because the reload time of TZM --> PU is about 4 times higher than ZM ---> PU can provide.

Also is a non-standard installation form when a podium was built for the fire control radar (PRC). This was necessary not because reducing the effect of radar horizon against low flying target the specific location demanded it. The S-200 site was built next to a forest which caused issues tracking of low flying targets it was easier to build a platform instead clear the whole forest.



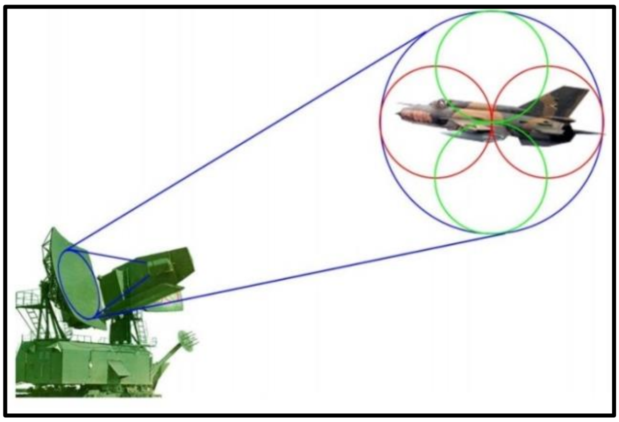
The main parts of the K1V (GRAU designation is 5N62) fire control radar is the followings:



1. Continuous wave 4.5 cm wavelength target illumination signal, transmit-only antenna
2. Continuous wave 4.5cm wavelength target illumination signal, receive-only antenna
3. KRO missile flight status down-link signal, receive-only antenna
4. NRZ (IFF) antenna

The 5N62 radar use 4.5 cm wavelength (6.6 GHz), the effective output power of the illuminator is 85 kW which made possible to detected even smaller tactical fighters from about 200-300 km in normal Mono-Chromatic Emission, but in FKM and FM mode the detection range is smaller. (See later.)

One of the new key features of the S-200 was the monopulse antenna which is much more jam resistant comparing to the antenna systems of Dvina/Volkhov/Neva; the new system is immune the angle deception and inverse amplitude modulation jamming methods. The principle of the monopulse antenna is explained on the drawing right below.



The 1.4 degree wide pencil beam is used during target acquisition, if the target is closer than 200 km. The 0.7 degree narrow pencil beam is used during target acquisition, if the target is further than 200 km and during target tracking.

The continuous wave signal is emitted in the (blue) pencil beam. The reflected signal is received by the smaller square antenna, splitting it into three beams, (blue, red, green), where two beams are double pencils (red, green).The target tracking system seeks to minimize the signal across the two double pencils and maximize the signal at the blue pencil beam.

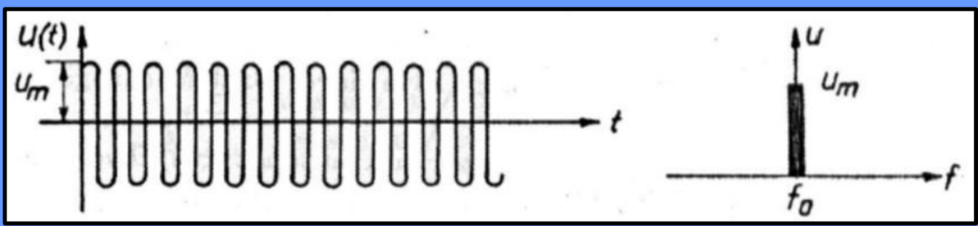
The RPC can emit three main different modes which are the followings:

- МХИ (MHI) Mono-Chromatic Emission. MHI is the primary mode for target tracking, the RPC emitting a continuous sinusoidal wave. The returned radar echo’s Doppler shift is measured. With this mode, the target’s speed, elevation, and azimuth (V, ε, β) parameters are measured. As the emitted energy is in a very narrow frequency spread, the target detection range is the highest in this mode. If the target's

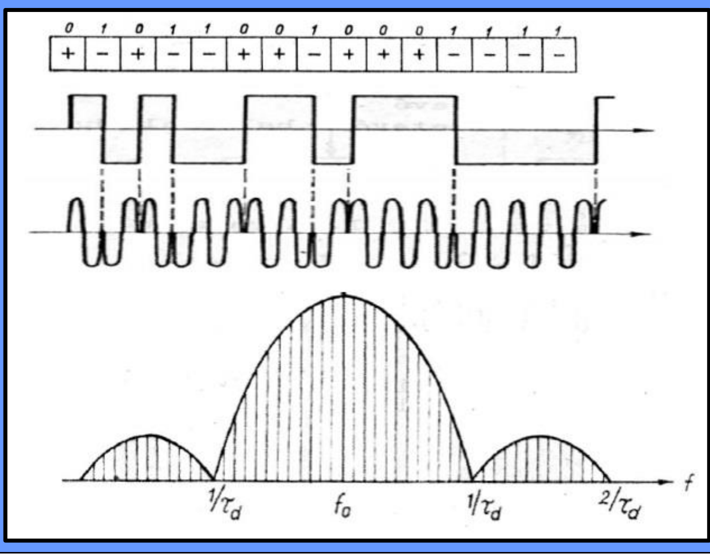
angular speed is less than 40 m/s (78 knots / 145 km/h) (the target is on tangential path) it cannot be detected using this mode

- ФКМ (FKM) Phase-Code Manipulation. FKM mode of the RPC is used to measure target range besides the speed, elevation, and azimuth (V, D, ε, β). During this mode, the emitted sinusoidal wave is phase modulated by a digital code. As the emitted energy is across a wider frequency spread, the target detection range is shorter than in MHI. If the target's angular speed is less than 60 m/s (117 knots / 250 km/h) it cannot be detected using this mode. This mode is used target acquisition to determine the distance of the target.
- ЧМ (FM) Frequency Modulation. FM is a sub mode of the RPC it can be used with MHI or FKM. During this mode the emitted sinusoidal wave is frequency modulated. As the emitted energy is across a wide frequency, the target detection range is even shorter than in MHI or in FKM. The advantage of using this mode is that the target's angular speed can be zero and still be tracked in azimuth and elevation. This mode is useful against close targets in beaming maneuver.
- АС-РПЦ (AS-RPC) AS-RPC is a sub mode of the RPC it can be used with MHI, or FKM. During this mode, the digital computer is continuously calculating the target's predicted path. In case the target's angular speed drops below the minimum, and the target cannot be tracked using the FM sub mode, the RPC will track the target's predicted path.

Explanation of the listed modes above MHI mode means in idealized model the emitted signal has only a single frequency component. Of course this is idealized in reality this means the emitted power is in a very narrow frequency range.



In FM mode the generated frequency is same all the time but the result of the phase change can be seen on the spectra of the emitted signal besides the main frequency component other frequency appear even the modulated base signal has only a single frequency component. This means the power of the emission and reflection in the base frequency is smaller therefore the detection range is also smaller. This is the downside of measuring the target distance comparing to MHI mode.



The combined features of the missiles and fire control radar provided the very large engagement range comparing to any previous Soviet SAM system. Not only the engagements zone the maximal target speed and target altitude also is better comparing all other previous SAM systems. The S-200 family had the following main missile types during its career:

SAM system type	*Missile*	*Missile range*	*Missile altitude*	*target speed*
-	-	*km*	*km*	*km/h* *m/s*
Sz-200A Angara (SA-5A)	5V21 V-860P	17-150	1-35	360-3500 100-975
Sz-200A Angara (SA-5A)	**5V21N V-870**	**17-150**	**1-35**	**360-3500** **100-975**
Sz-200V Vega (SA-5B)	5V21V V-860PV	17-180	0,3-35	0-3500 0-975
Sz-200M Vega-M (SA-5B)	5V28 V-880	17-240 (255)*	0,3-40,8	0-4300 0-1200
Sz-200M Vega-M (SA-5B)	**5V28N V-880N**	**17-240** **(255)***	**0,3-40,8**	**0-4300** **0-1200**
Sz-200VE Vega-E (SA-5B)	5V28E V-880E	17-240 (255)*	0,3-40,8	0-4300 0-1200
Sz-200D Dubna** (SA-5C)	5V28M V-880M	17-300 (400)***	0,3-40,8	0-4300 0-1200

* **Against subsonic targets**

** **Until end of the Cold War only 15 batteries were manufactured**

*** **Only with counting VZRB from the main site**

Missiles marked with red has 25kt yield TA-18 nuclear warhead which had 60% larger yield than the V-760 15D (Guideline Mod.4) missile of the S-75M3 Volkhov.

The 5B14S warhead of the missile is the largest ever made warhead for any SAM. Total weight is 217 kg the explosion is 90 kg in the wared rest of the is shrapnel it contained 21000 pcs 3.5 g and 16000 pcs 2g weight small steel balls which can reach 1000-1700 m/s impact velocity. (The 450 kg warhead of BOMARC was made only for training not for combat use.)

The size of the missile restricted the antenna diameter of the guidance system which had impact on engagement range against smaller tactical fighters. Regardless both the P-14F long range target acquisition radar and fire control radar are able to detect MiG-21 size targets from about 200-300 km the missile can lock such target before the launch only from about 130 km in MHI mode against a fighters in a beaming maneuver tracking range is even more smaller.

The later explained engagement diagrams do not illustrate this restriction against tactical fighters the practical engagement range is much smaller than the maximal even in a non-jamming environment. Because of this against one of the main threat the AGM-28 Hound Dog the engagement zone also was smaller.

To establish the large engagement zone it had to be design such missile and guidance which was able to use many different time-thrust characteristics for different missile trajectories depending of the distance and

speed of the target. For this purpose was necessary to have a digital computer in the memory of computer are stored in blocks the different possible parts of the time-thrust characteristics.[11]

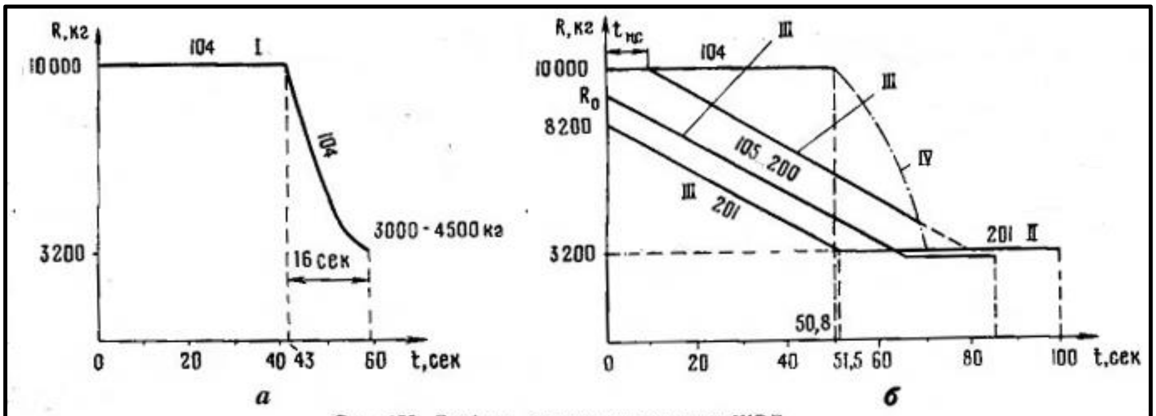


Рис. 158. Графики регулирования тяги ЖРД

Time-thrust characteristics of different programs

Program block are the followings:

- program block I., constant 100 kN thrust then thrust decrease to 32 kN
- program block II., constant 32 kN thrust
- program block III., decreasing thrust with constant gradient, 0,97 kN/sec
- program block IV., fuel dumping program to make the missile lighter to increase its maneuvering capability

Combining these blocks the memory stores 97 different time-thrust characteristics before launch these programs are read out (download) from the 5E23A SRP digital guidance computer of the missile. The program selection is automatic based on the target parameters (distance, speed, altitude, etc.)

- Above 80 km target distance program 104 is used. For 43 seconds the program block I. is used, thrust is decreased to 32 kN at 60th second of the flight when missile run out from fuel. Missile speed is about Mach 6 at this point.

- Against medium and high level targets closer than 80 km programs between 104 and 201 are used. According to the selected program block III. is used as way to deplete completely the fuel. If this is not possible before the impact in terminal phase fuel is dumped with program block IV.

- Against low level targets program 201 is used. For 50 seconds program block III. then for 50 seconds block II. is used. The trust does not reach the maximal 100 kN the maximal speed of the missile is only about Mach 3 At 38 km the fuel is depleted the missile very quickly deaccelerates.

Regardless of different thrust characteristics at low and medium level the air friction caused such heat load and stress on the missile what restricted the engagement envelope for more than a decade. The missile had such long flight time and such high speed which caused issues at low level engagement or even "re-entry" of the missile below 10 km at long engagement range. [12] On the engagement zone below is visible the range-altitude restriction.[13]

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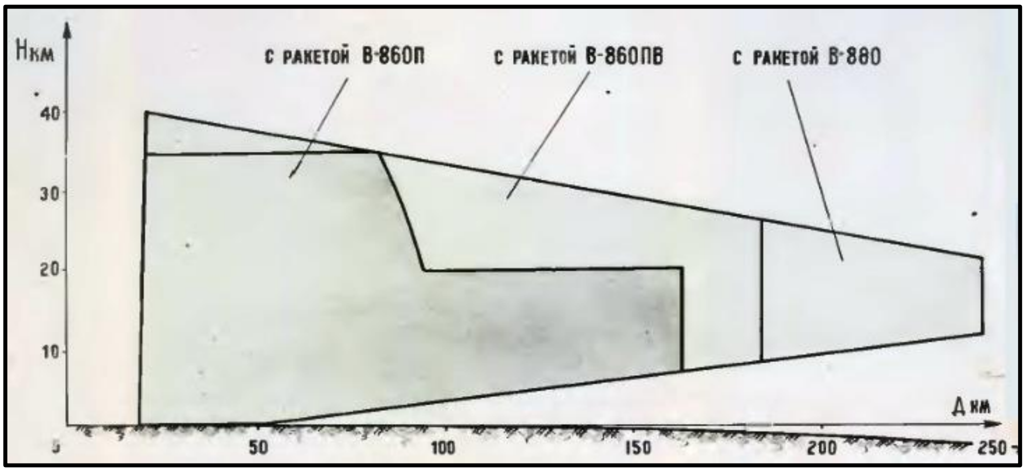
[11] http://historykpvo.narod2.ru/
Учебник ЗРК С-200.Состав,принципы действия и боевые возможности - учебник по с200 , page 238.

[12] The heat load could damage the electronics but also could be a result deformed nose cone which may made uncontrollable the missile because of the asymmetric airflow.

[13] http://historykpvo.narod2.ru/ - Альбом разработок ЦКБ Алмаз 1947 - 1977 гг, page 8.



Because of the heat load at longer range initially the minimal engagement altitude for the Angara and Vega systems were higher than the radar horizon. At 150 km distance the radar horizon is at 1.5 km altitude, at 200 km at 3 km altitude and at 250 km at 4.5 km altitude. On the diagram above we can see the minimal engagement altitude values with V-880 missile is far higher than the radar horizon for example at 250 km distance the minimal engagement altitude is about 10 km. The problem was not unique the S-300 SAM family also suffered initially and had similar restriction in the engagement zone. Introducing the quartz ceramics nose cone solved the problem at mid-end of ‘80s it made possible extending the engagement zone (with 99% probability) to the radar horizon or very close to it.

Not only the thrust but the missile trajectory also depends on the target distance two main leading methods are available:

- Up to 80 km target distance proportional guidance is used
- Above 80 km target distance following by the launch missile continues the climbing with 48 degree pitch rate up to 20 km then proportional guidance is used

On the next page is the engagement zone of the S-200V Vega with different missiles:

- Red region shows the engagement zone with 5V28 and 5V21V missiles.
- Blue region shows the engagement zone with 5V28 missile.
- Green region shows the engagement zone with 5V28 missile against subsonic, non-maneuvering jamming target, only against jamming target is under the radar horizon the zone.
- Red arrow shows and example path of an AGM-28 Hound Dog missile at 17 km altitude with 700 m/s speed with about 180 km offset distance.
- Black arrow shows and example path of an B-52 bomber at 17 km altitude with 280m/s speed with about 220 km offset distance.

On the image above the regions with marked I, II and III shows the limitation of the engagement zone according to target altitude, speed and offset distance. The values in degrees means the maximal angle between the velocity vector of the target and the missile which are the consequences are the guidance leading and missile maneuvering capability. We can judge at what distance and speed can be engaged a subsonic bomber or a fast AGM missiles such AGM-28 or AGM-69.

I. q = 102 degree, target speed is less than 500 m/s, target altitude is at least 5 km.
II. q = 90 degree, target speed is less than, mint 500 m/s, target altitude is smaller than 5 km.
III. q = 82 degree, target speed is between 500 and 1200 m/s.

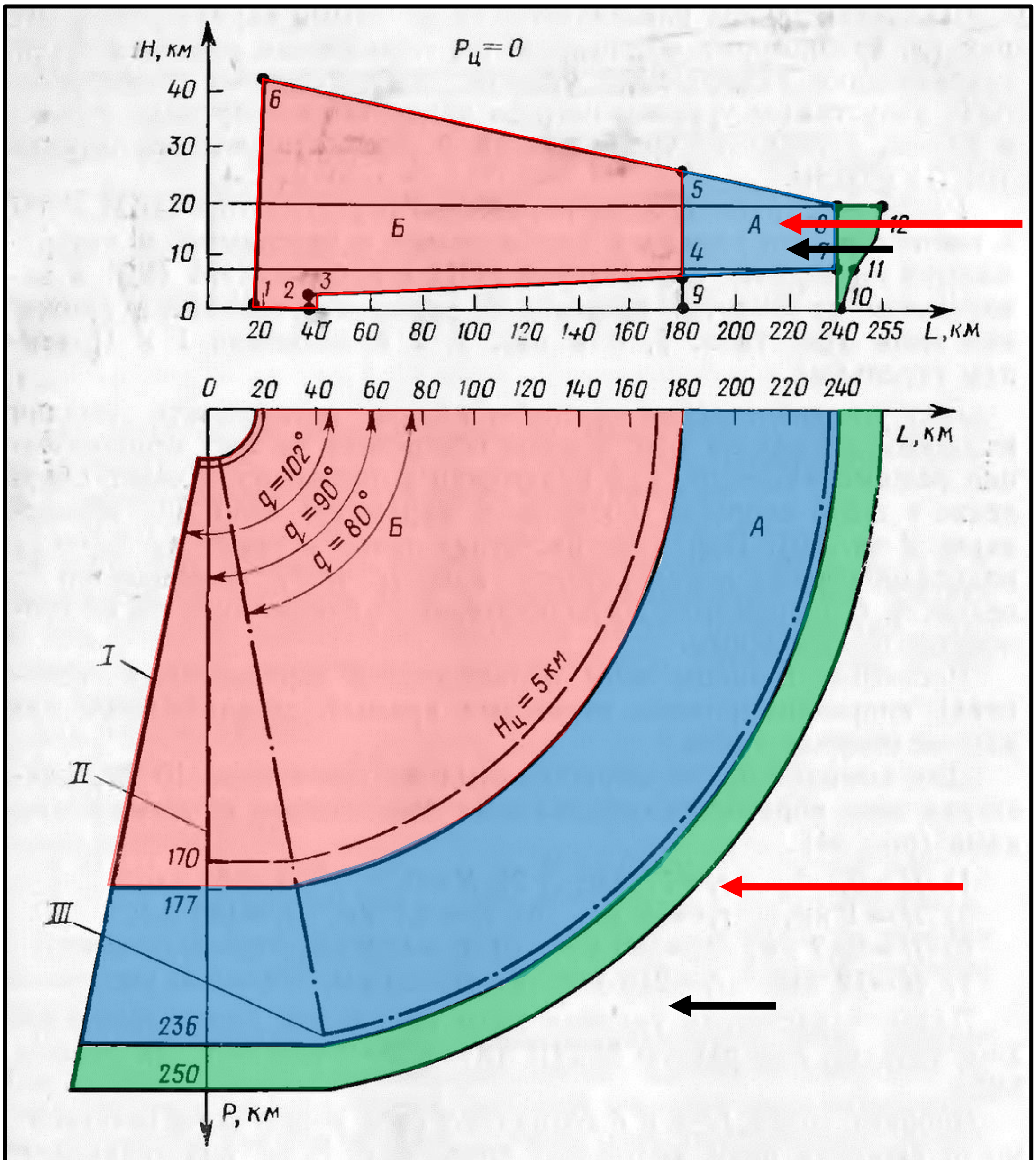
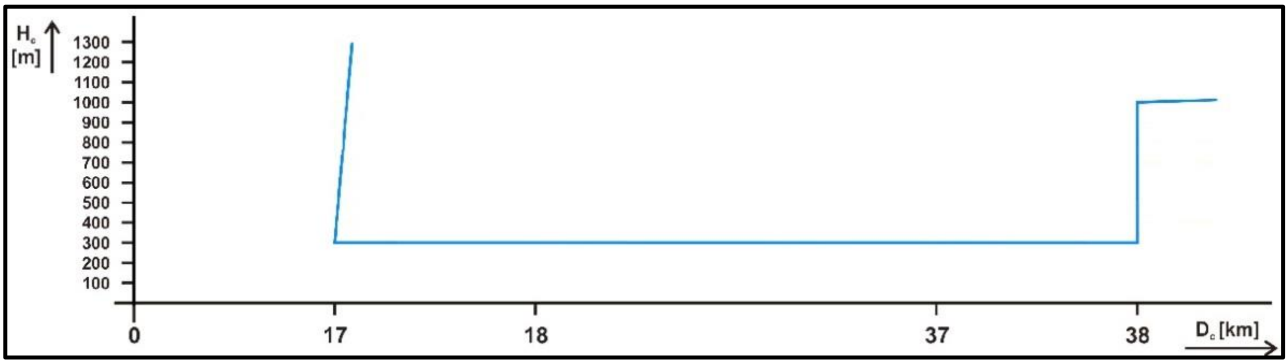


Рис. 35. Расчетные границы зоны поражения, зоны обстрела и предельные дальности стрельбы для ЗРК, доработанных по перечню 10 Вг:
I — $q=102°$ при $V_ц \leq 500$ м/с и $H_ц > 5$ км;
II — $q=90°$ при $V_ц \leq 500$ м/с и $H_ц \leq 5$ км;
III — $q=80°$ при 500 м/с $< V_ц \leq 1200$ м/с;
А — для ЗУР 5В28; *Б* — для ЗУР 5В28 и 5В21В(А)

Engagement zone of the S-200V Vega [14]

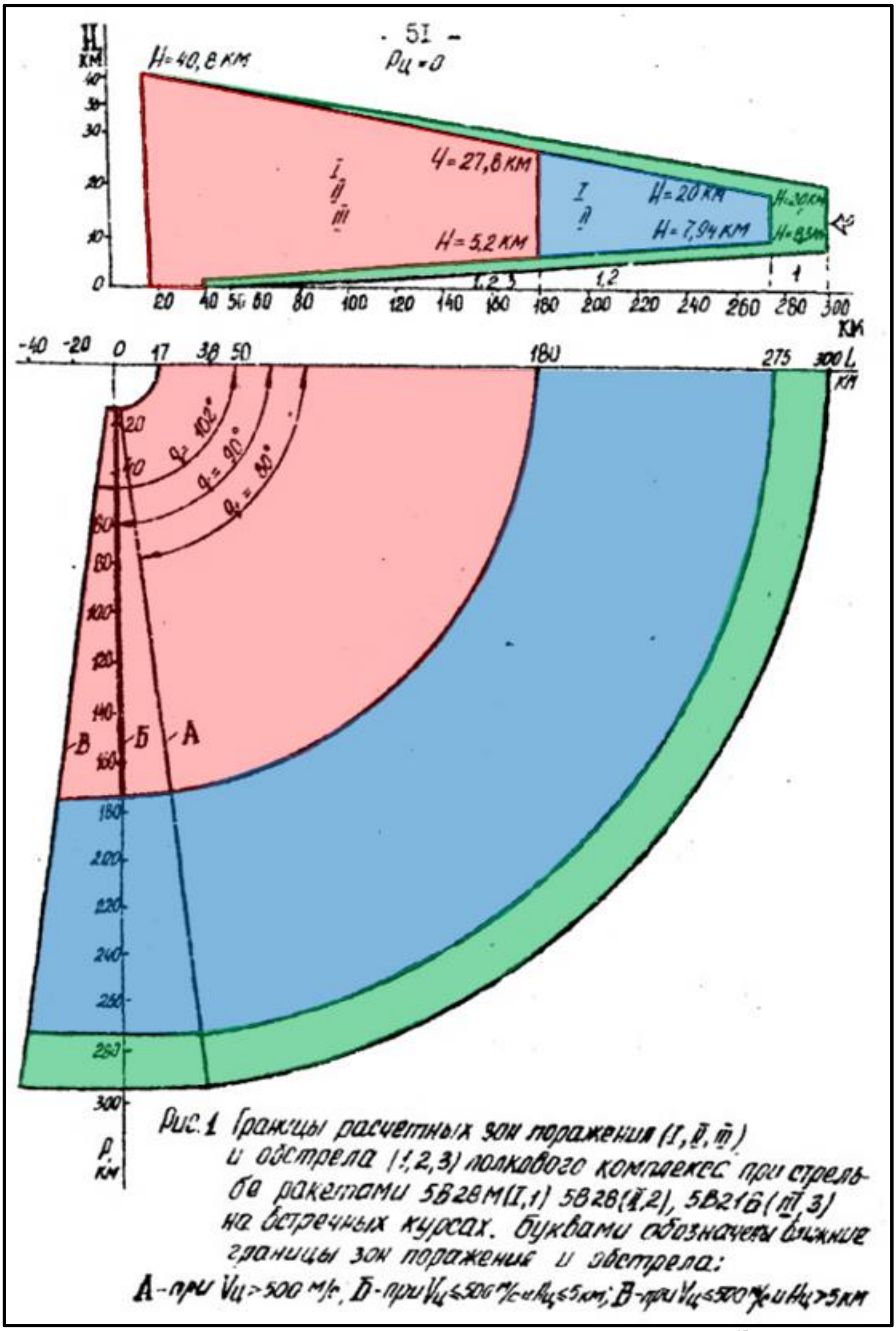
The engagement zone at close range and low altitude with higher resolution is on the next page. The zoomed region is the region around the 1, 2 and 3 points on the image above.

[14] http://historykpvo.narod2.ru/
Пособие по изучению правил стрельбы комплекса С-200В-поясн к пс200, page 173.



Engagement zone of the S-200E Vega against low level targets at close range with 5V28 missile. The 5V28 missile had 1000 m minimal engagement range between 17 and 38 km horizontal distance.

The engagement zone of the S-200D Dubna was increased to 300 km thanks to the upgrades on the fire control radar. We can see on the engagement zone diagram that minimal engagement altitude reaches the radar horizon because of the new quartz ceramics nose cone of the 5V28M missile. On the image the following page the green region shows the difference between the engagement zone of Vega and Dubna S-200 subvariants.



Engagement zone of the S-200D Dubna against incoming targets [15]

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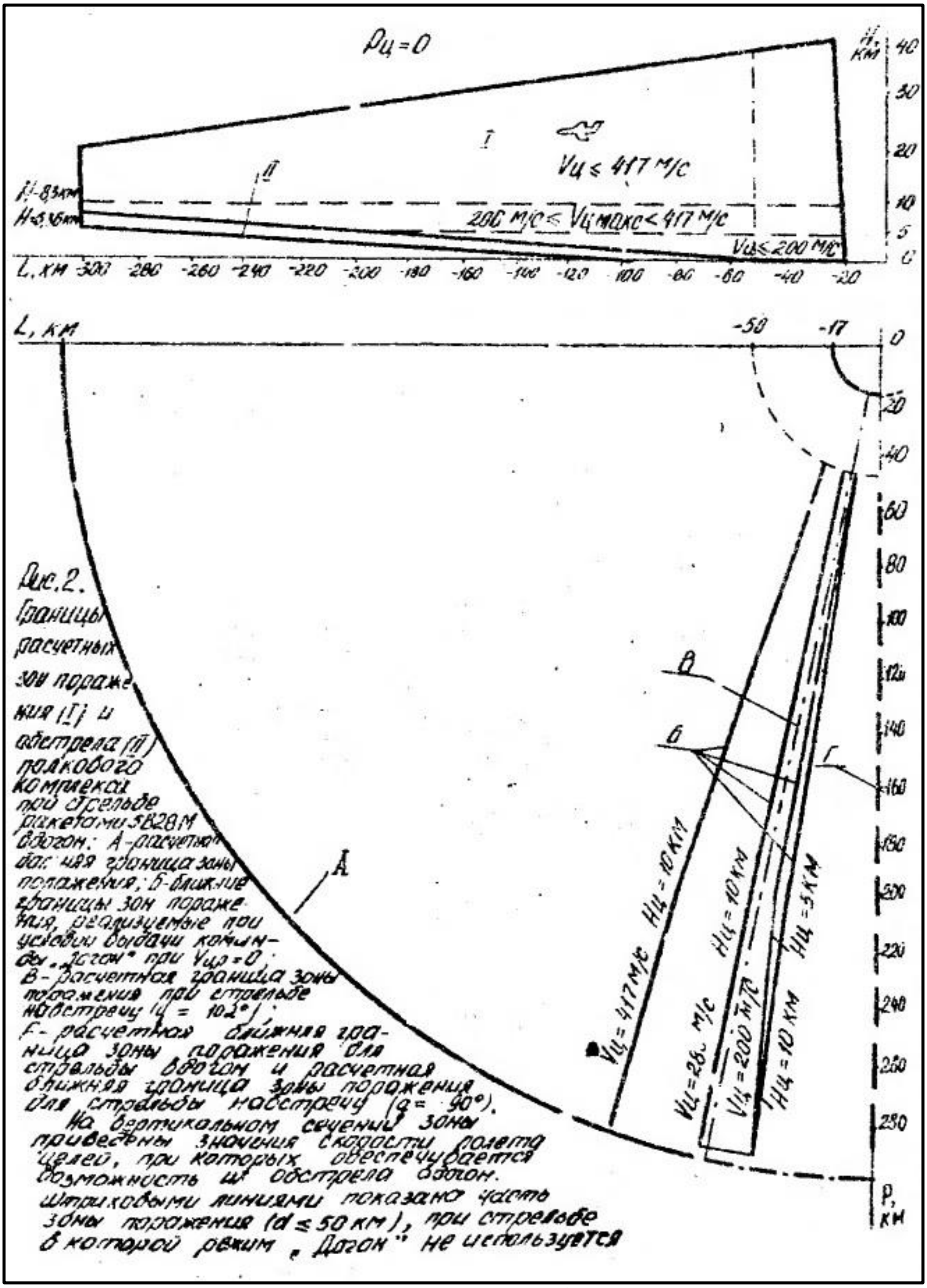
[15] *http://historykpvo.narod2.ru/*

Правила стрельбы зенитными управляемыми ракетами зенитных ракетных дивизионов системы С-200- правила стрельбы с-200д (Дубна), page 51.



Engagement zone of the S-200D Dubna against receding targets, [16] ***the maximal target speed is considerably smaller even with 0 km offset target distance, only 417 m/s***

[16] http://historykpvo.narod2.ru/

Правила стрельбы зенитными управляемыми ракетами зенитных ракетных дивизионов системы С-200-правила стрельбы с-200д (Дубна), page 52.

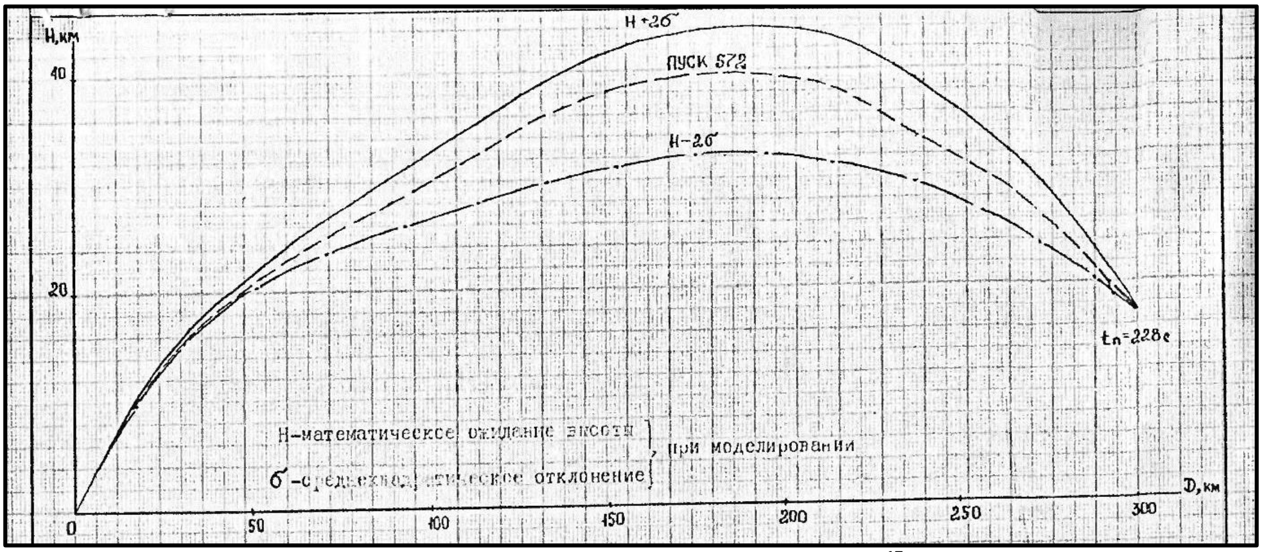
The used waveform of the fire control radar is also a limitation for engagement zone as well as the radar cross section (RCS) of the target and its angular speed. Basically the S-200 does not measure target distance during the whole guidance it calculates it. The battery gets the data about the target from the long range target acquisition radar of the site of from other source via data link of automatized command post/system. The radar locks on target using a very short time the FKM mode for distance measuring then the MHI mode is used and continue the tracking based of speed and flight direction of the target.

The problem for the system targets what pass next to the S-200 site which have less and less angular speed especially if they have much smaller RCS than a large bomber. The lock or tracking range of the missile because of different modes than MHI can be reduced the real engagement range against cruise missiles, tactical fighters and strike fighters less or much than the distances we can read from diagram above. RCS of targets typically is larger from side view but in case of small angular speed FM mode has to be used instead MHI. (Some target specific engagement diagrams are in the attachments.) Because all of listed factors above against incoming and receding targets above certain speed the engagement zone is not all-round are gaps where the system is not able to track a target.

The engagement zone all of S-200 subvariants is restricted by the missile launch. The missile can be launched only with 48 degree PU angle and similar to S-75/125 systems as long as booster stage has not been jettisoned the missile cannot perform any maneuvers. The turning capability of the missile at slow and low altitude is also smaller comparing to higher speed and altitude regions. At sea level 6G, at 20 km 10G, at 35 km is only 2.5G. This is why has 17 km minimal engagement distance against very low flying targets because after the launch missile has to turn towards to ground and loose altitude.

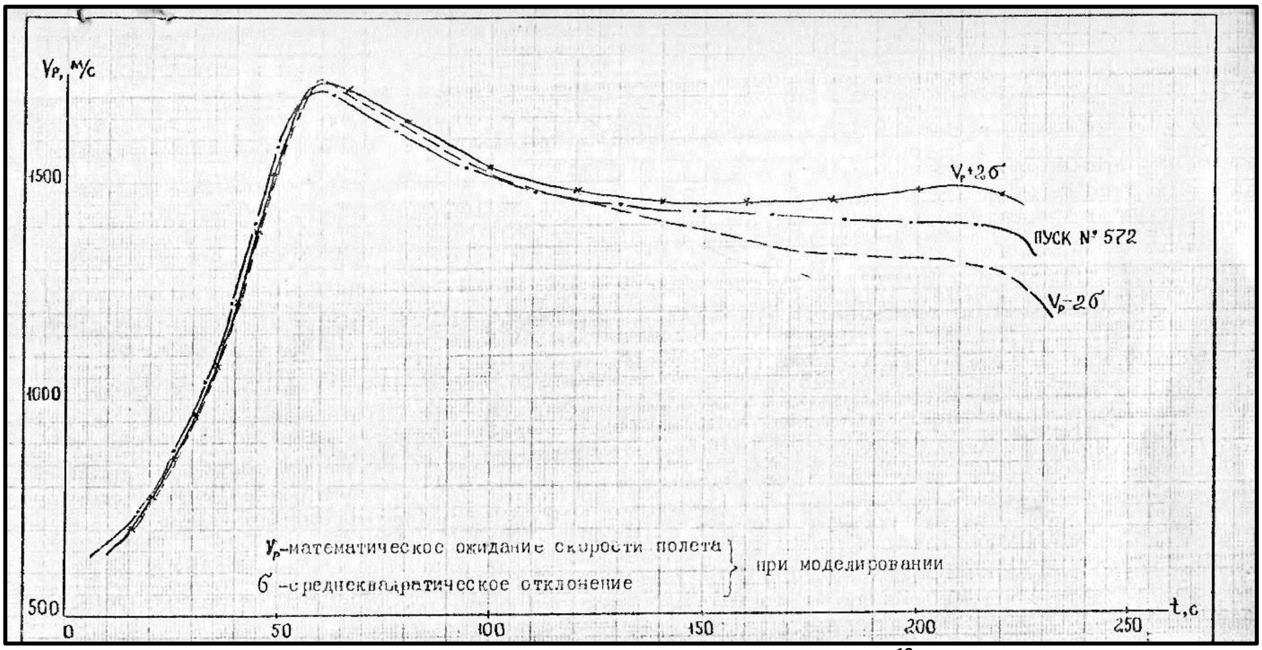
(The speed of missile after jettisoned the booster stage is about 650 m/s which means the turn radius with 6G maximal overload is about 7 km.)

On the two following diagrams below are measured speed, time and distance data from live fire tests. The missile can reach 40 km altitude and 300 km horizontal range, after 228 seconds of the launch was reached the 300 km distance. Regardless of about 1250-1400 m/s speed



Missile trajectories of the S-200, measured data[17]

[17] http://historykpvo.narod2.ru/
Отчет результаты испытаний ракеты 5В28 на дальности встречи 290...300 км при стрельбе по мишеням МР-9ИЦ-А-с200 на 300км, page 6.



Missile time-speed data of the trajectories above [18]

The S-200 has a very theoretical feature, in theory is capable to do quasi simultaneous target engagement in long range engagements against intercontinental bombers. S-200 can perform target relock in case because of any reason target tracking is interrupted. The key target tracking can be interrupted intentionally by turning off the fire control radar.

Let's just assume a tactical situation where a 6 B-52 bombers incoming from the same direction to an S-200 Vega site with two batteries. The two batteries launch two missiles (each battery 1-1) then another two (each battery 1-1) when the missiles are about from 120 km the site on the same targets. In ideal case missiles hit two targets and guidance crew get feedback from missile (the just before the detonation missile sends back a signal) while the missiles of the second salvo are still flying to targets.

At this point the fire control radar is turned off the missile of the second salvo loses the target but they are about 60-100 km from the remaining bombers which are quite close to the two already downed targets. In his case with trained crew relock is possible and fire control radar can track two different targets therefore missiles are guided against different targets compared than they were launched and could hit these new targets.

Of course this kind of capability needs a very specific tactical situation and good crew but the hardware in theory makes possible to carry out such engagement. (In manuals of the system such usage is not explained because is very theoretical.)

(Even the older Volkhov was able to relock the target and way used this feature with automatized command systems, see later in another chapter.)

[18] http://historykpvo.narod2.ru/
Отчет результаты испытаний ракеты 5В28 на дальности встречи 290...300 км при стрельбе по мишеням МР-9ИЦ-А-с200 на 300км, page 7.

Finally – as usual – here are some galleries and video links about the S-200 SAM family.

http://www.ausairpower.net/APA-S-200VE-Vega.html

http://www.ausairpower.net/APA-S-200VE-Vega-Sites.html

https://www.youtube.com/watch?v=OZFP1iqdqxA

https://www.youtube.com/watch?v=J8clY5Xlb64

https://www.youtube.com/watch?v=Mjvg9eGtNSQ

https://www.youtube.com/watch?v=tJG6nnM86bQ